



The NASA Applied Sciences Program: Volcanic Ash Observations and Applications

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Co-Author Acknowledgement

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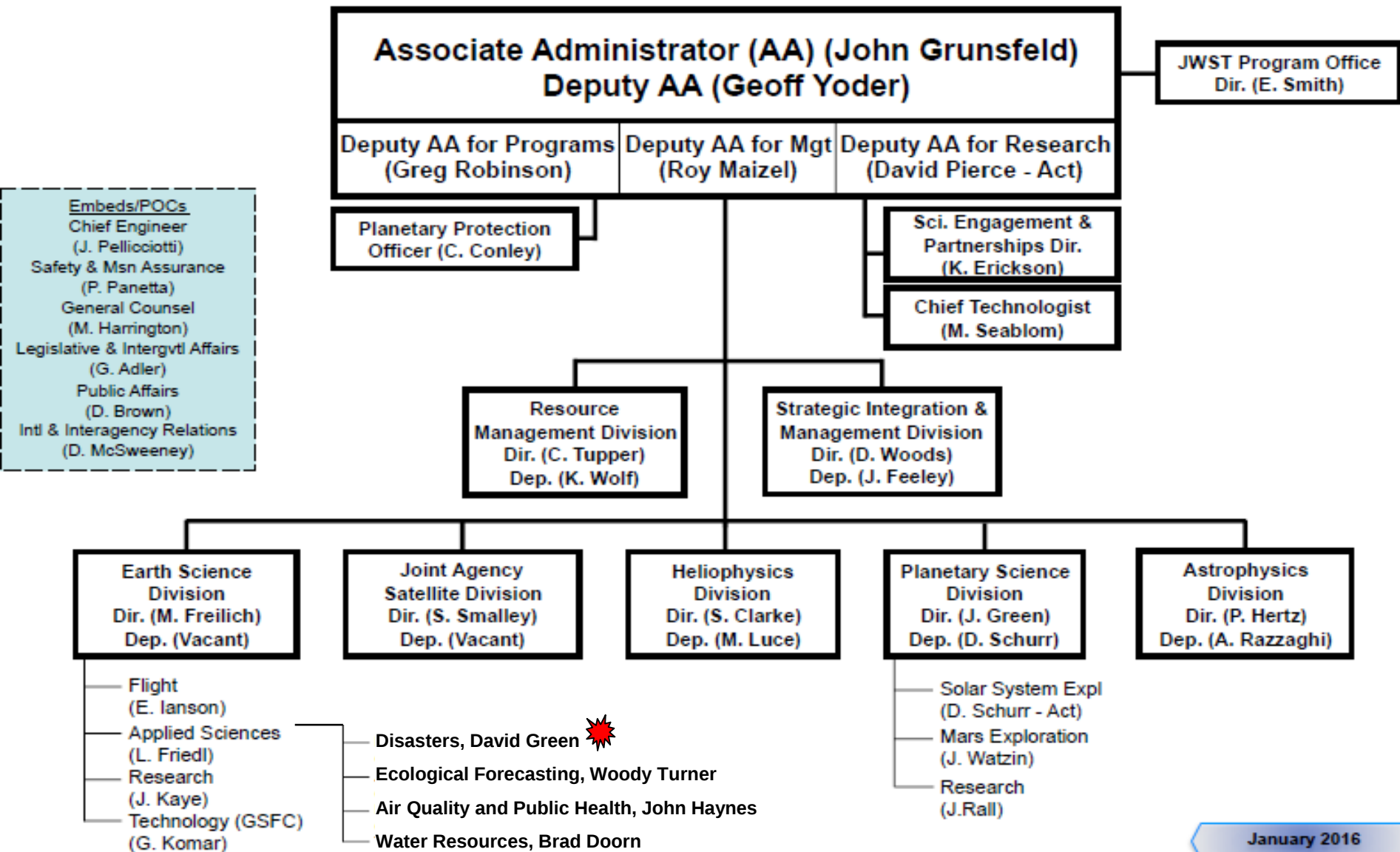
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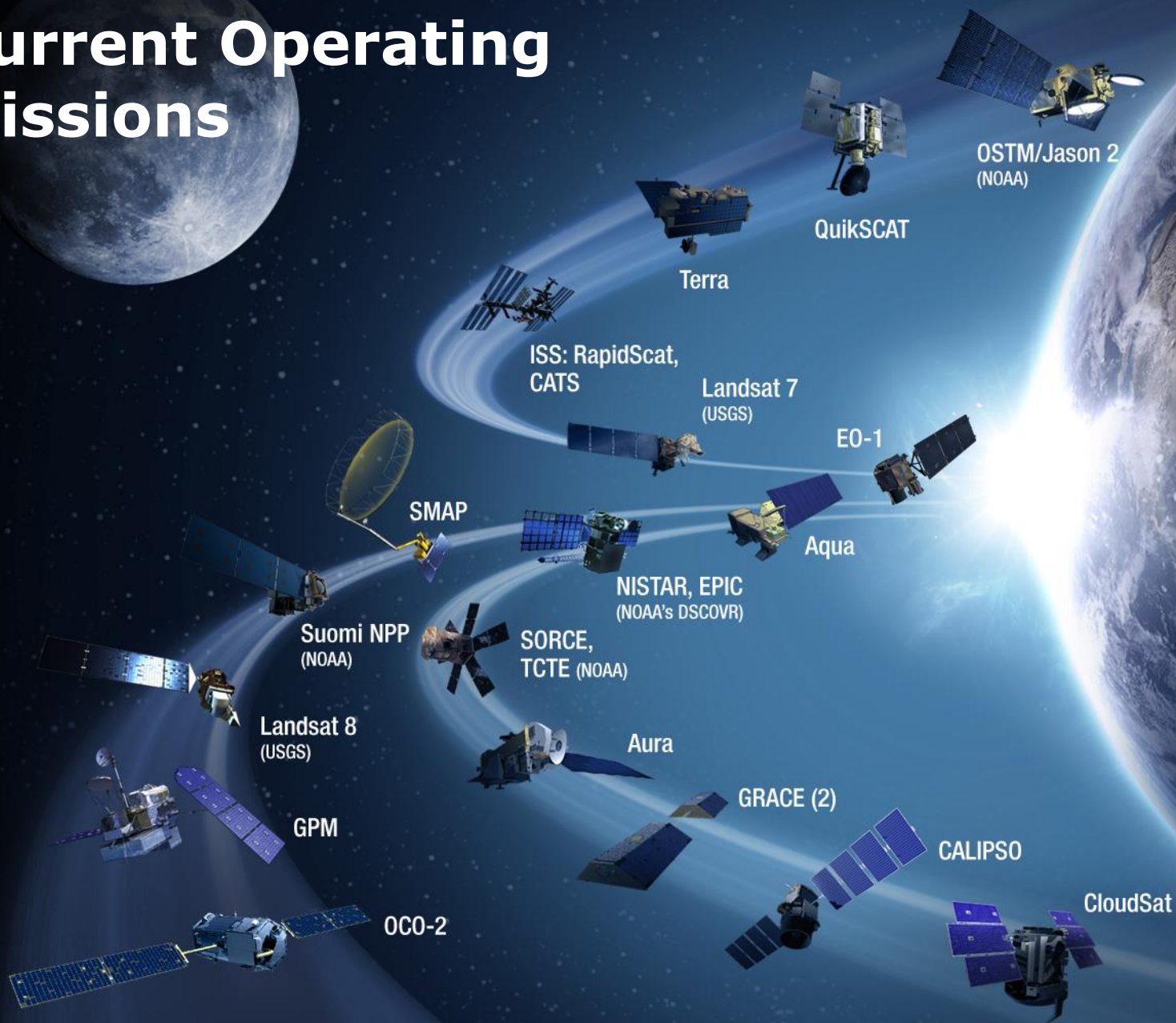


NASA Applied Science Program

Disasters Focus Area

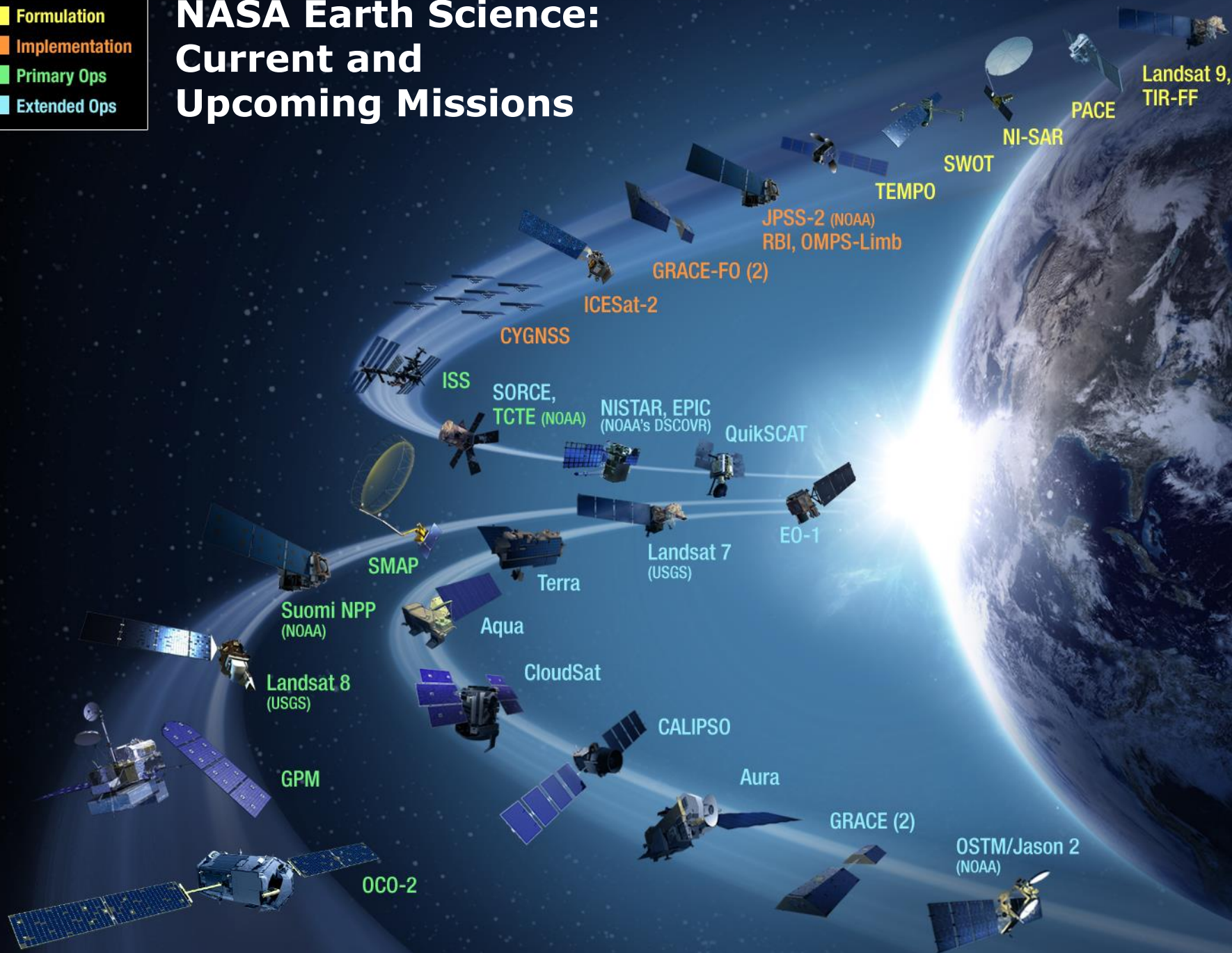


NASA Earth Science: Current Operating Missions



- Formulation
- Implementation
- Primary Ops
- Extended Ops

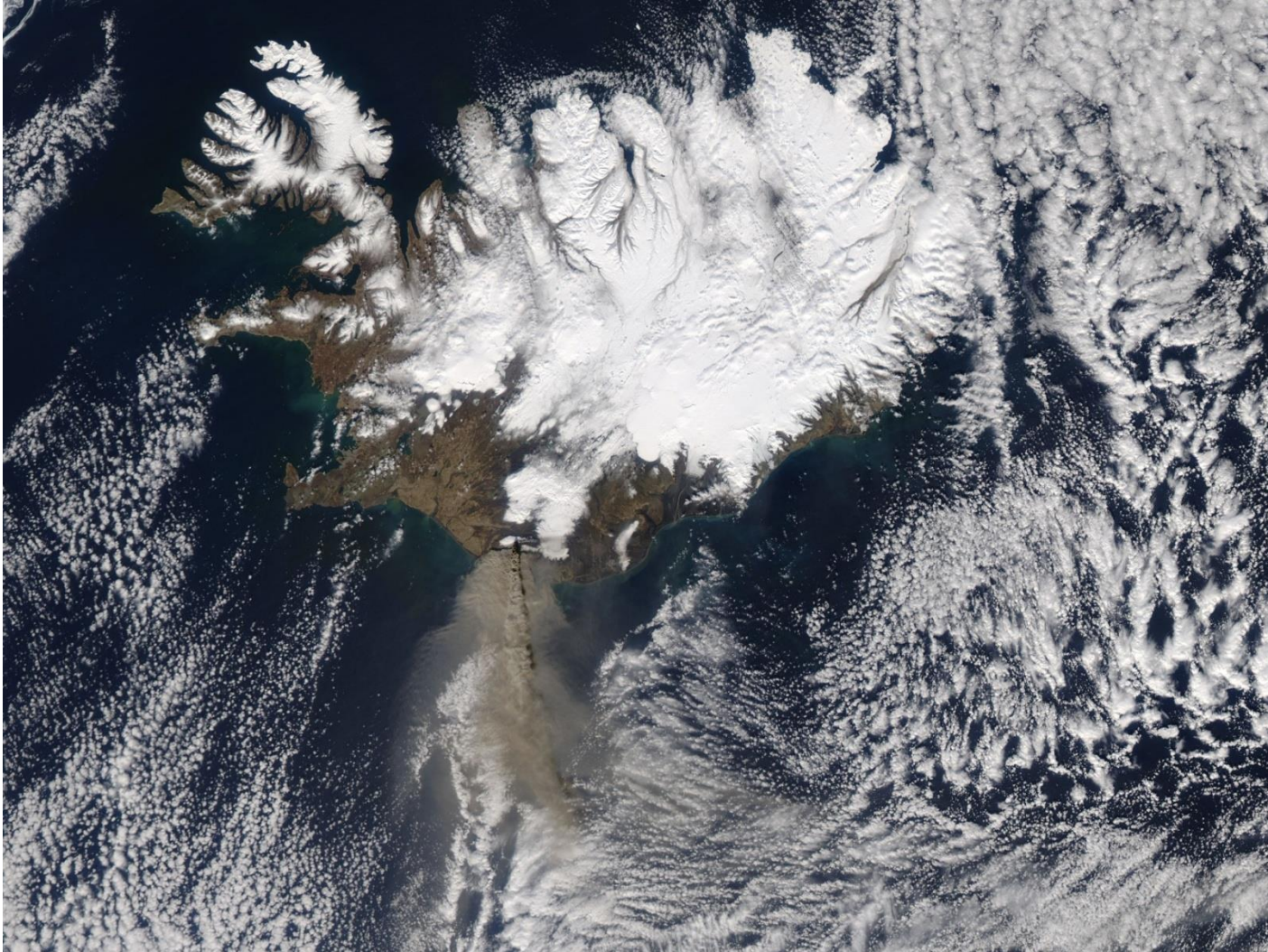
NASA Earth Science: Current and Upcoming Missions





MODIS Image

Eyjafjallajökull Volcano, 17 April 2010



Satellite imagers provide the best source of information concerning the location of volcanic ash. When one thinks of imager data, typically this is what typically comes to mind.



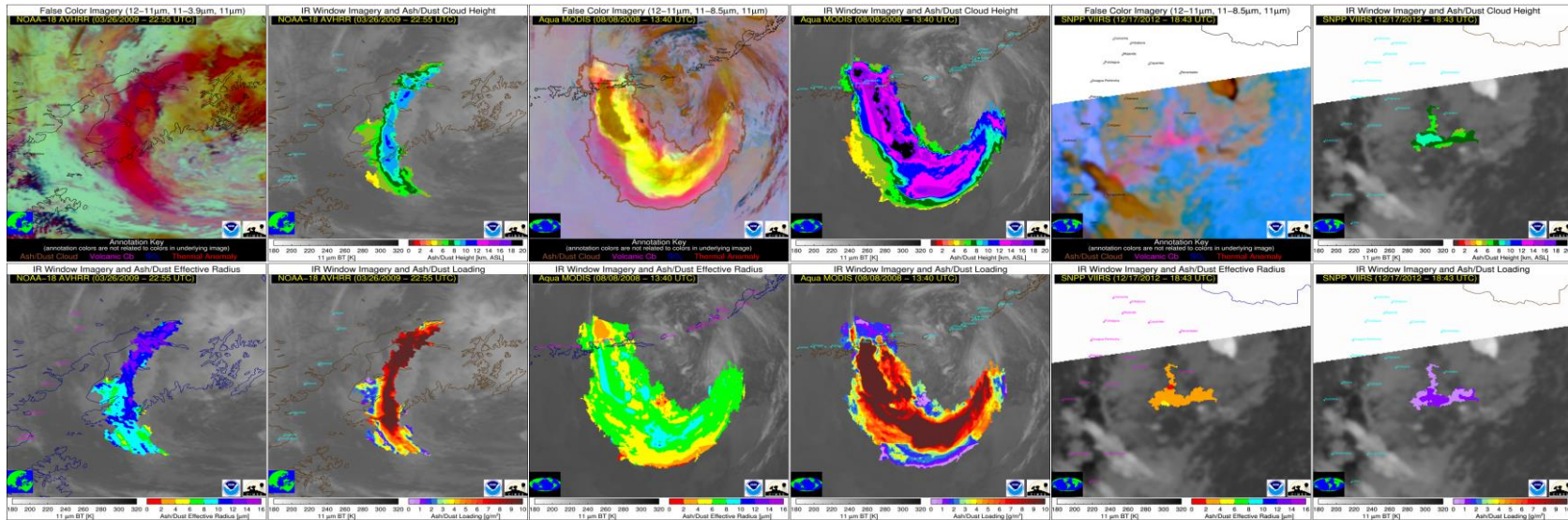
Multi-spectral Imaging: Making Full Use of Space-based Imagers for Volcanic Cloud Monitoring

NOAA and MetOp AVHRR

Terra and Aqua MODIS

SNPP-VIIRS

LEO

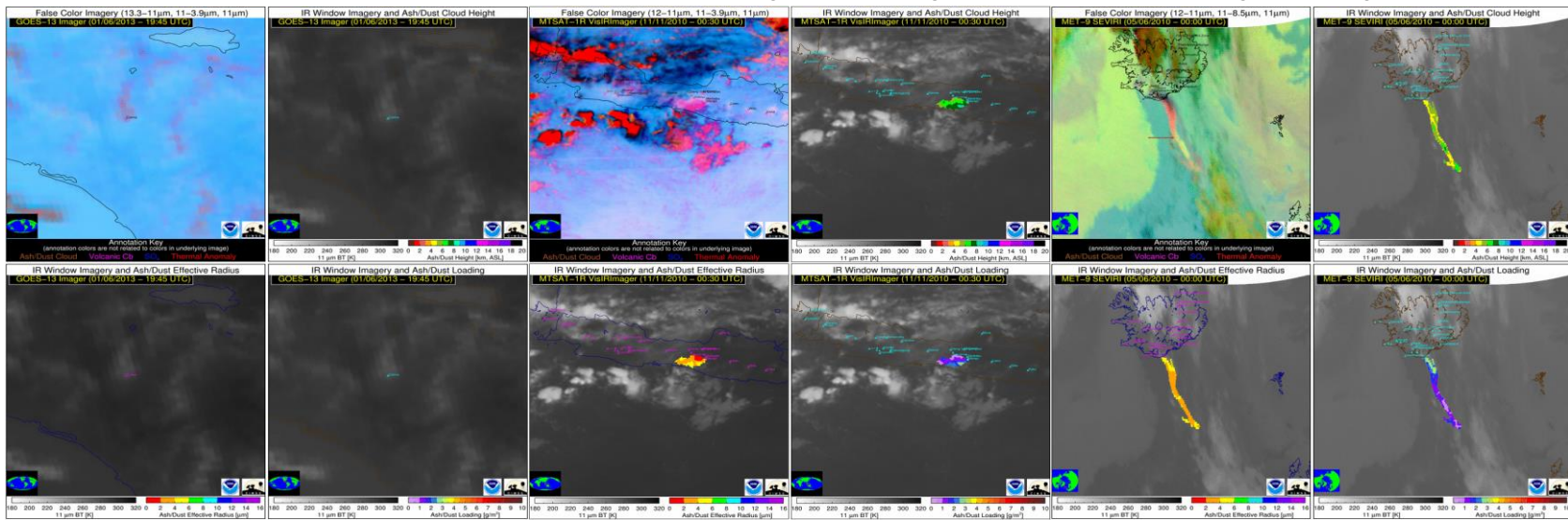


GOES-13-15

MTSAT-(1r and 2)

Met-(8,9,10) SEVIRI

GEO

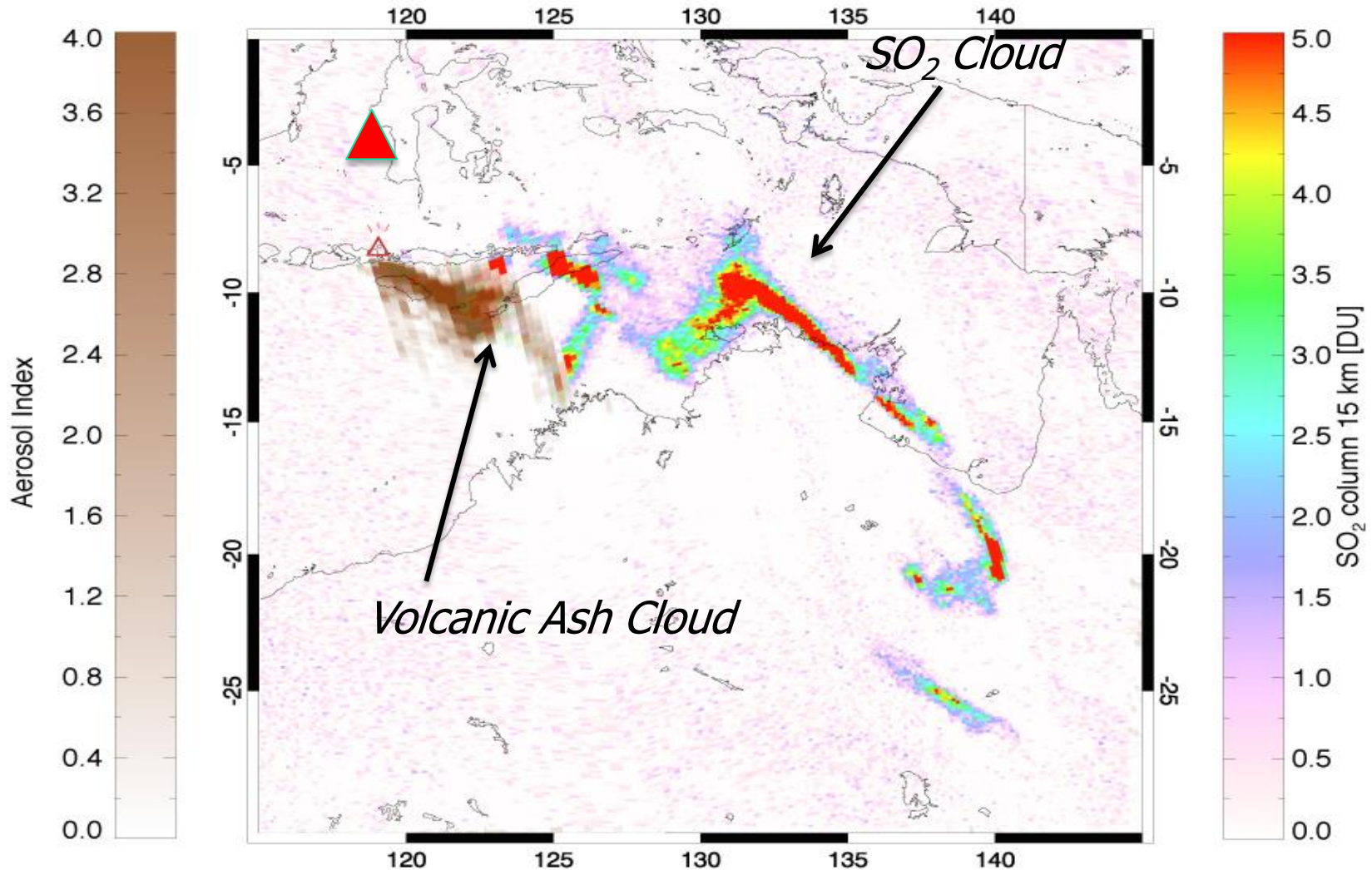




Horizontal Mapping Of Volcanic Ash: SNPP/OMPS NRT SO₂ & Ash Index

Eruption of Sangeang Api

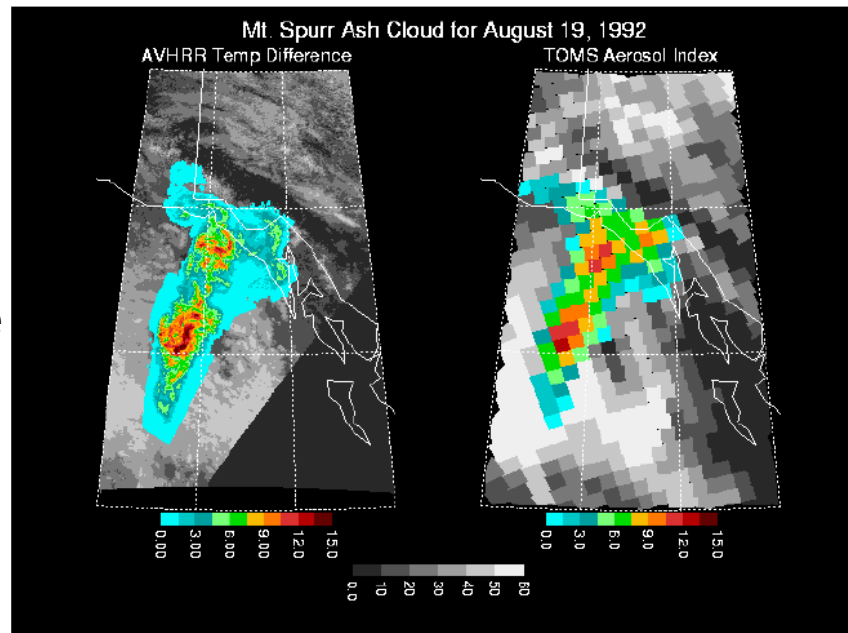
NPP/OMPS May 31 2014 (04:35-06:25 UT)





Imager and UV Sun-photometer Complementarity

- IR ash detection:
 - Plume must be transparent
 - Water hides ash
 - Plume temperature contrast with underlying surface
 - Detectable day and night
 - Low concentration not detectable
- Fresh ash clouds:
 - Dense, must wait until sheared to thin layer
 - Full of water, ice which masks detection



IR: T11-T12

UV ash: AI

- UV ash (AI) detection:
 - Scattering by ash differs from Rayleigh scattering
 - Sunlight necessary
 - Low concentrations are detectable
- Fresh ash clouds:
- Detected upon eruption
 - Independent of water content
 - Not detectable at night



NASA Direct Readout data processing at FMI and UAF/GINA



Direct Broadcast from Aura and S-NPP satellites



Receiving station in Sodankylä, Finland (FMI)



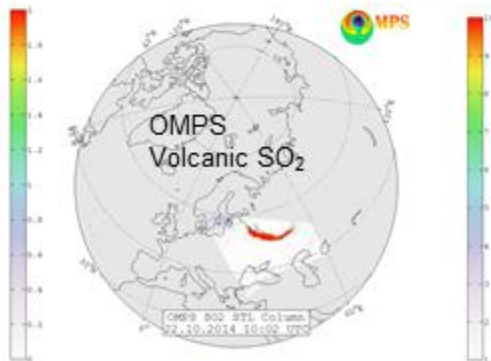
Receiving station at GINA/UAF in Fairbanks Alaska



OMI and OMPS DR processing in Sodankylä

NASA/GSFC Direct Readout Laboratory and NPP ozone PEATE create software package for local processing of NPP DR data

OMPS DR Processing at UAF/GINA



FMI's WWW and FTP services. Available within 20 min after data reception.

GINA's WWW and FTP services to Alaska Volcano Observatory. Available within 20 min after data reception.

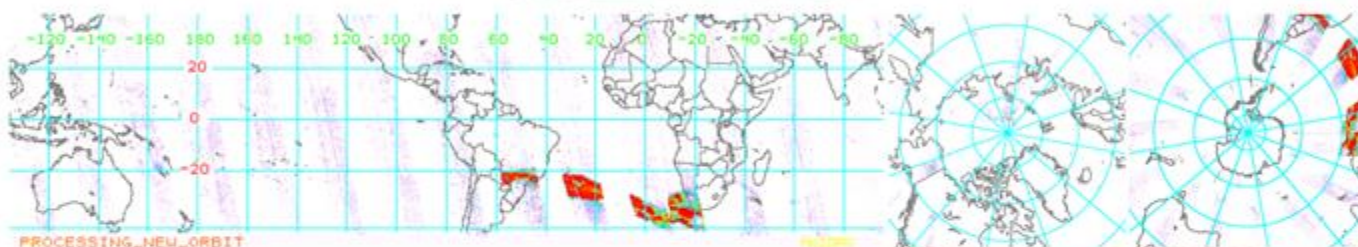
<http://sampo.fmi.fi/volcanic.html>

Aura/OMI SO₂ data integrated into NOAA/NESDIS volcanic alert system and web site



Latest OMI SO₂ Column 5Km - 24-Hour Composite Images

Important Information for OMI Data Users



Current OMI SO ₂ Composites	Tropics	Northern Hemisphere	Southern Hemisphere
Current & Previous Digital Images GeoTiff, NetCDF, McIDAS, GIF	Tropics	Northern Hemisphere	Southern Hemisphere

Latest OMI_SO₂ Column 5Km by Volcano

Alaska, USA	Aleutian Islands, Alaska, USA	Anatahan, Mariana Islands	Cascade
Central America	Comoro Islands	Eastern China	Ecuador
Etna, Sicily, Italy	Galapagos Islands, Ecuador	Hawaii, USA	Iceland
Japan	Java, Indonesia	Kamchatka, Russia	Mexico
Montserrat, West Indies	New Zealand	North Western Europe	Northern Atlantic
Northern Chile	Nyiragongo, DR Congo	Peru	Philippines
Papua New Guinea	Red Sea	Reunion Island	Southern Chile
Sulawesi Sangihe, Indonesia	Sumatra, Indonesia	Tanzania	Vanuatu, South Pacific

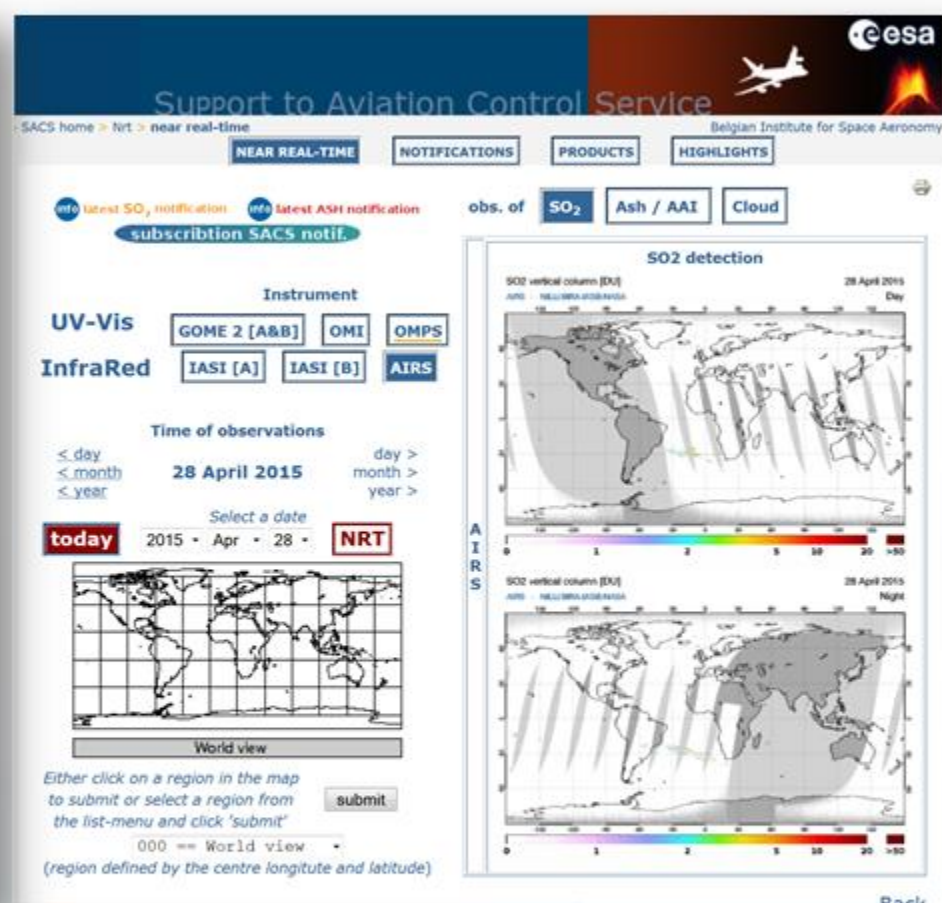
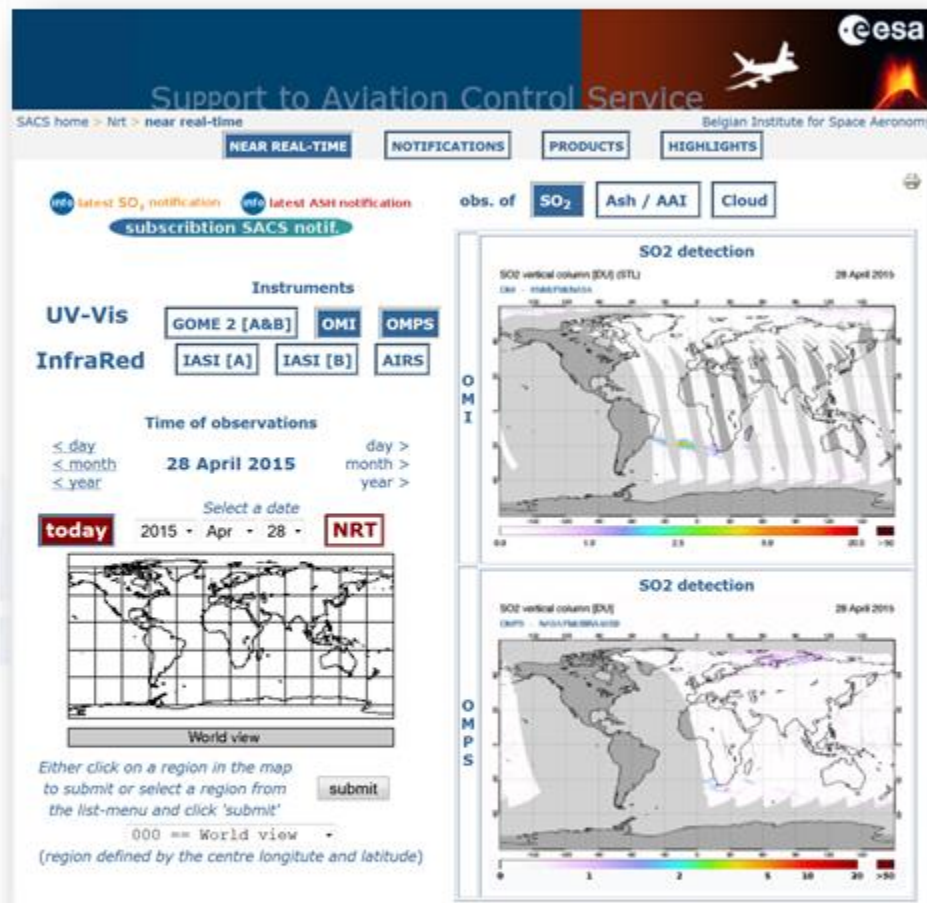
For OMI and AIRS SO₂ Alerts check the [OMI SO₂ Alert Site](#) and the [AIRS SO₂ Alert Site](#)

For science quality products check with [NASA GES DISC](#) and with the [NASA Global Sulfur Dioxide Monitoring](#)

<http://satepsanone.nesdis.noaa.gov/pub/OMI/OMISO2/index.html>

NOAA/NESDIS distributes NASA volcanic SO₂ data from Aura/OMI to operational users via Washington Volcanic Ash Advisory Center. NOAA issues automatic e-mail alerts notifications

AIRS, OMI, OMPS SO₂ data integrated into European SACS volcanic alert system



The European Support to Aviation Control Service (SACS) is using the operational volcanic SO₂ column and Ash Index data from Aura/OMI and SNPP/OMPS as well as volcanic SO₂ data from Aqua/AIRS produced by NASA to complement the information already available from the morning instruments (GOME-2A/B, and IASI-A/B). The project is supported by NASA applied Sciences Disaster Program: <http://so2.gsfc.nasa.gov>

SACS= global alerting system for volcanic SO₂ and ash

SACS is used by 278 subscribed users for many applications:

- Volcanological observatories
- VAACs/metOffices
- Pilots
- Airlines, private companies related to aviation sector
- National civil protection agencies
- Scientists
- Students, Professors
- Journalists
- Citizens

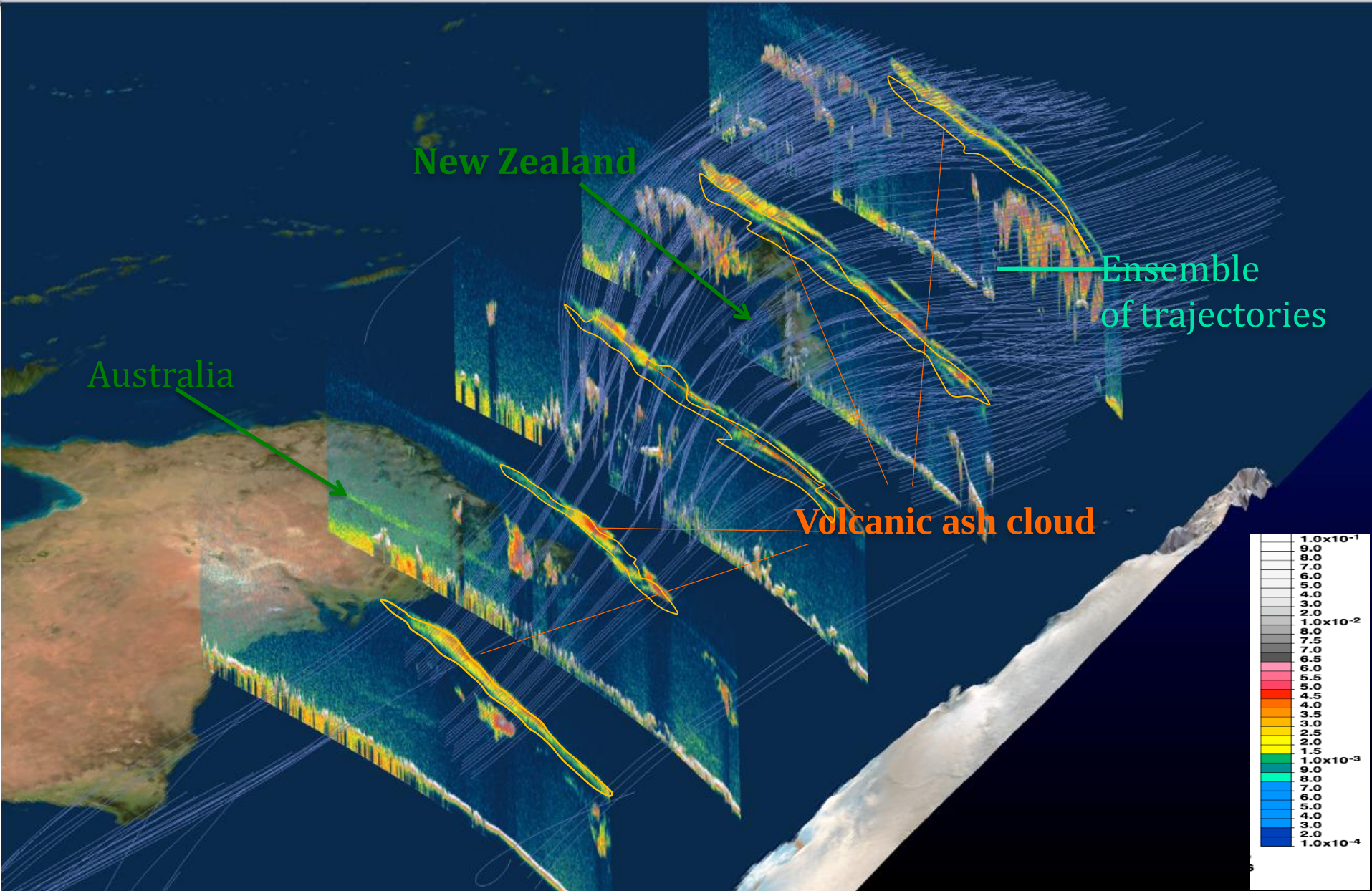


Adapted from Brenot et al. (2014), Support to Aviation Control Service (SACS): an online service for near-real-time satellite monitoring of volcanic plumes, Nat. Hazards Earth Syst. Sci., 14, 1099-1123, doi:10.5194/nhess-14-1099-2014, 2014.



Langley Research Center

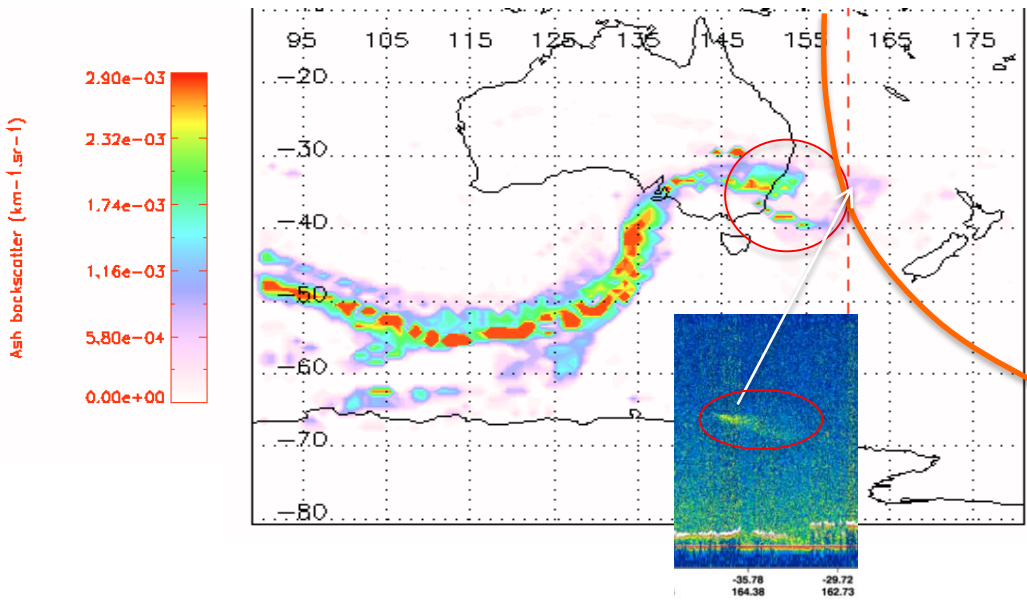
Enhanced Characterization: Assimilating Series of CALIPSO Curtains Into Dispersion Forecast Models



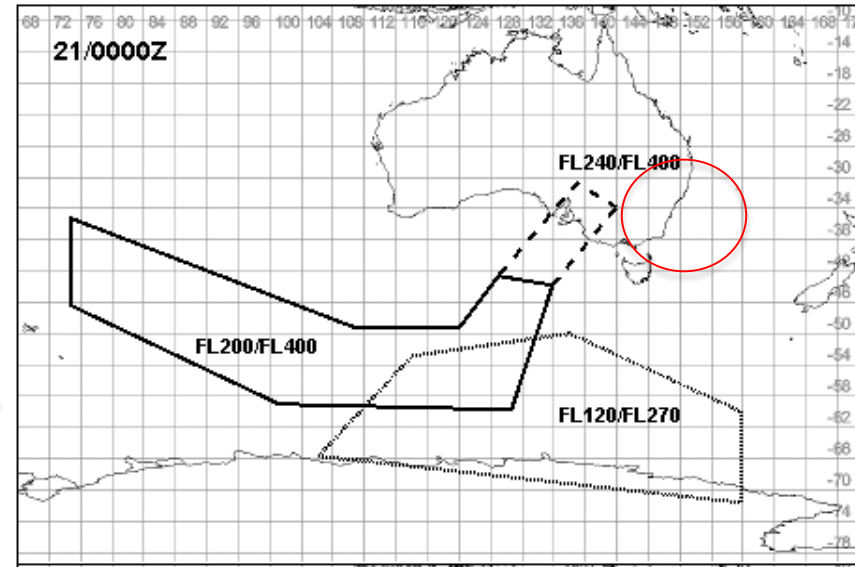


Result: Improving VAAC Advisories

CALIPSO-trajectory mapping

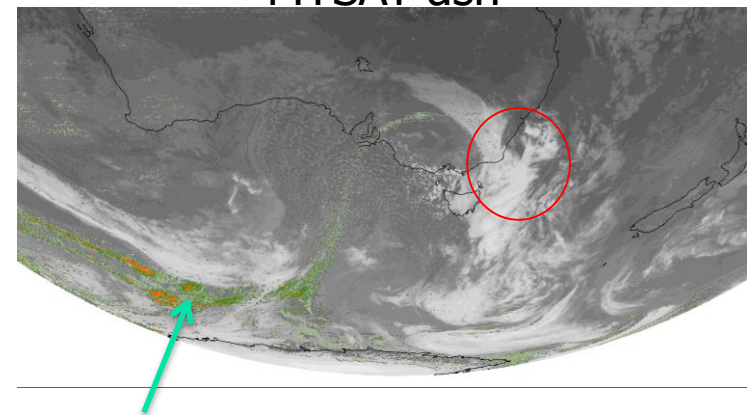


Volcanic Ash Advisory from Darwin VAAC



- Ash cloud masked by ash in MTSAT data over SE Australia (Sydney)
- Ash Advisory misses area over Tasman Sea
- CALIPSO-trajectory map captured the head of the plume on time as validated by a subsequent independent daytime overpass
- n.b. The plume depiction above is 2-D, whereas the model output is 4-D.

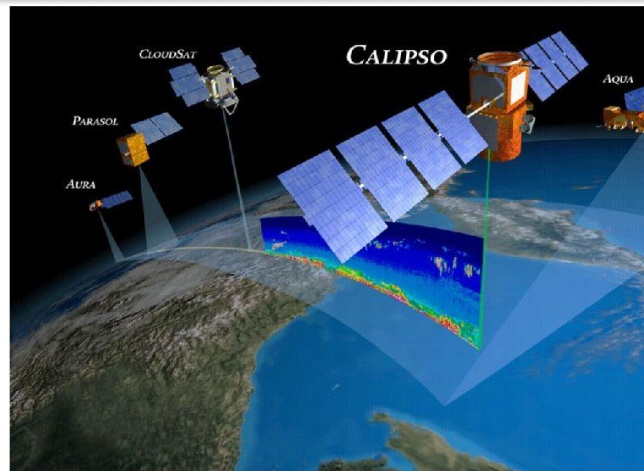
MTSAT ash



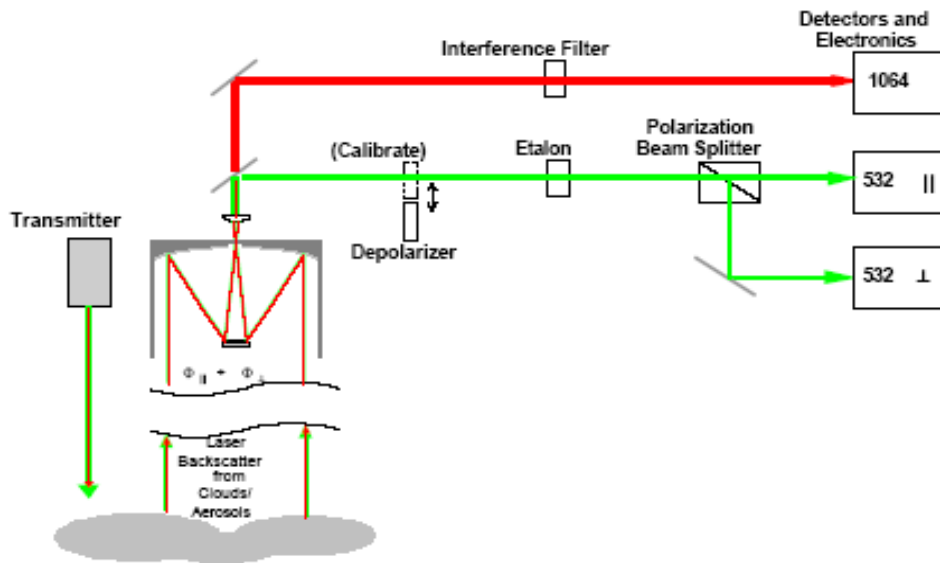
Visible Volcanic ash cloud



Caliop - The CALIPSO lidar



- Operating since 2006
- Polar Orbit
- Equatorial Crossing-time at 0130 and 1330 LET
- Repeat cycle of 16 days

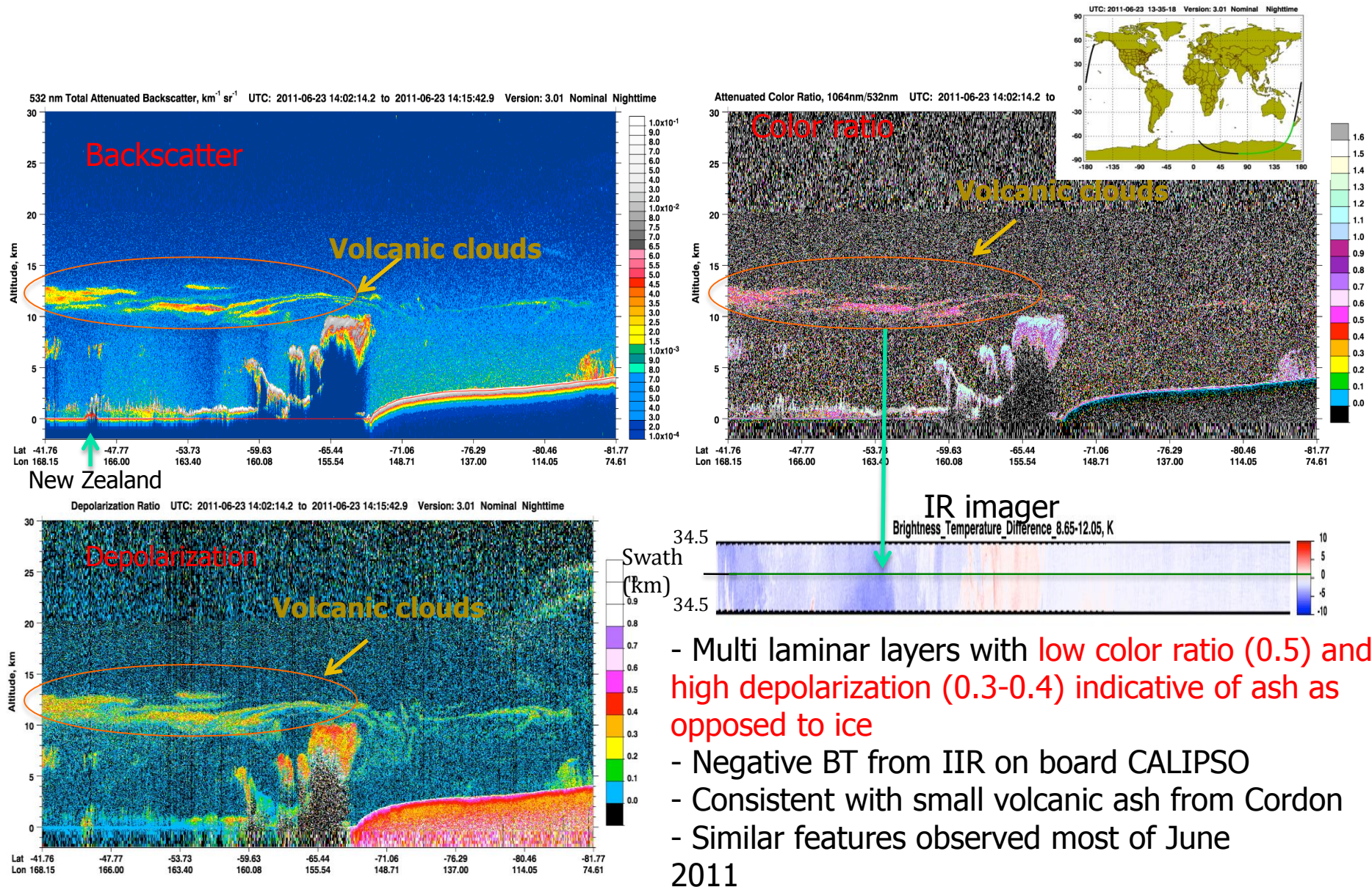


- Total Backscatter at 532 nm (density)
- Depolarization at 532 nm (geometry)
 - Color Ratio (1064/532) (size)

- **High vertical resolution (60 m)** of backscatter profiles
- Optical parameters provide unique capability to detect volcanic ash and its vertical structure



Cordon ash clouds over New Zealand observed by CALIPSO several weeks after the eruption



- Multi laminar layers with **low color ratio (0.5)** and **high depolarization (0.3-0.4)** indicative of ash as opposed to ice

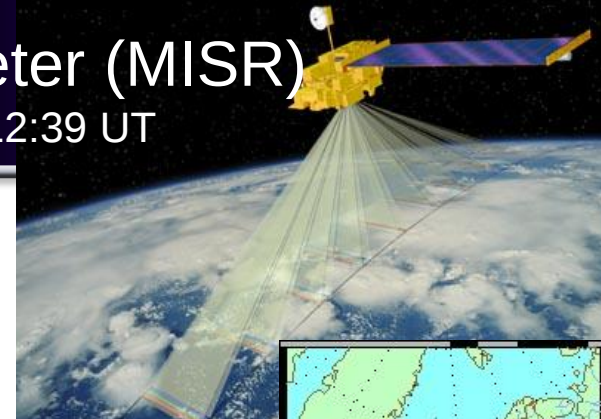
- Negative BT from IIR on board CALIPSO
- Consistent with small volcanic ash from Cordon
- Similar features observed most of June 2011



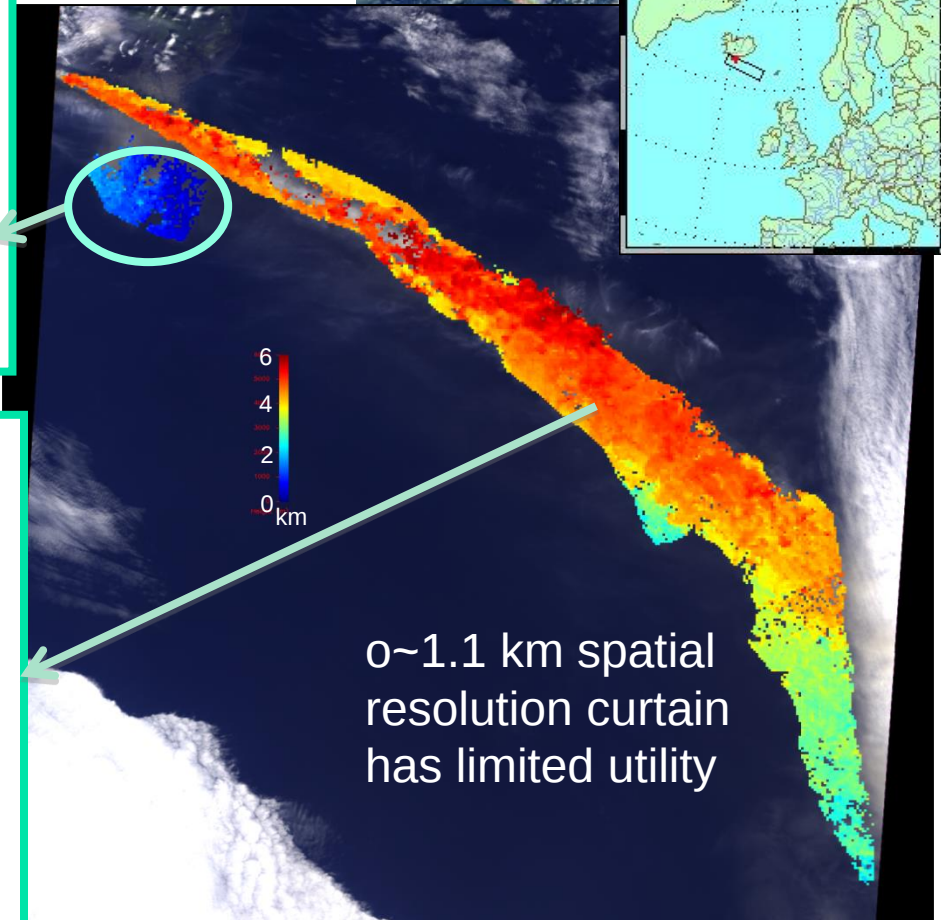
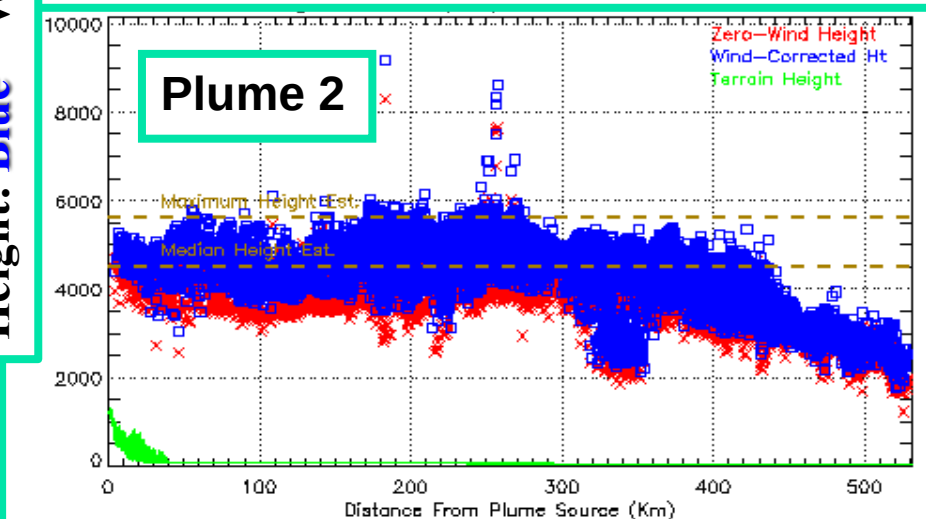
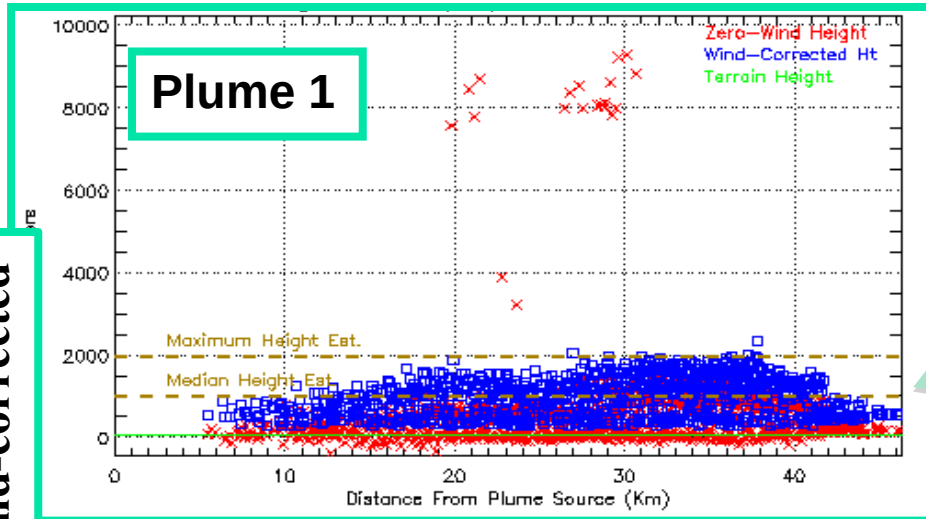
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Multi-angle Imaging SpectroRadiometer (MISR)

Adding Stereo-Derived plume heights, May 7, 12:39 UT



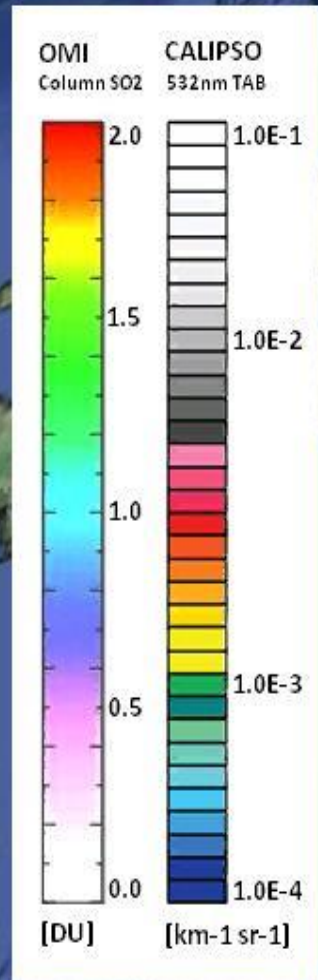
Height: Blue = Wind-corrected



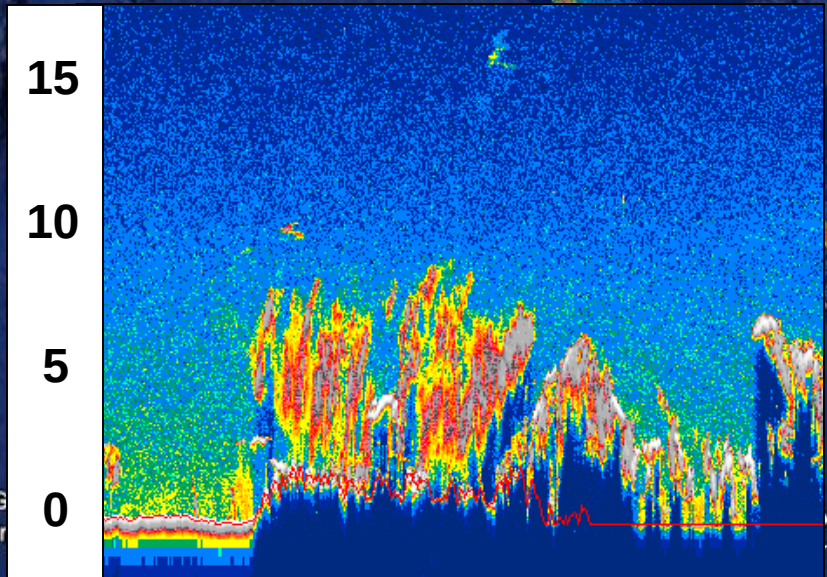


Mar 25, 2009 6:00 pm

Mt Redoubt, AK, 24 March 2009
Complementarity of SO₂ Horizontal
Mapping Using OMI/OMPS and
CALIPSO Lidar Vertical Curtains
(3-D Mapping for Lidar coupled with
HYSPLIT Model not shown).



OMI and OMPS provide information on the horizontal distribution of total column SO₂ and volcanic ash index while Caliop provides critical height distribution data of the volcanic aerosols.



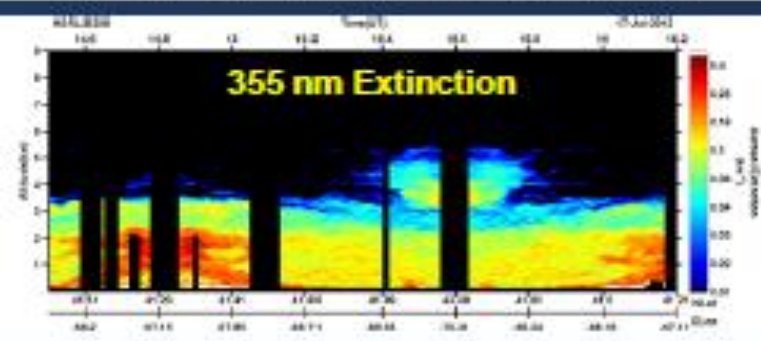
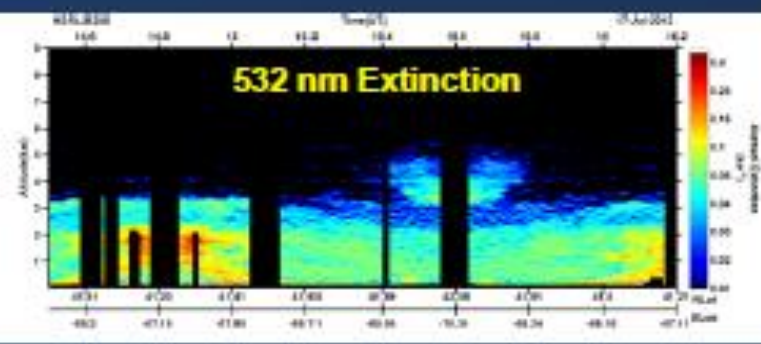
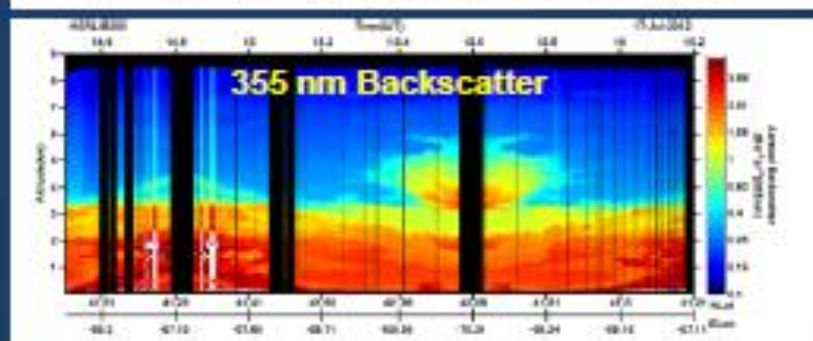
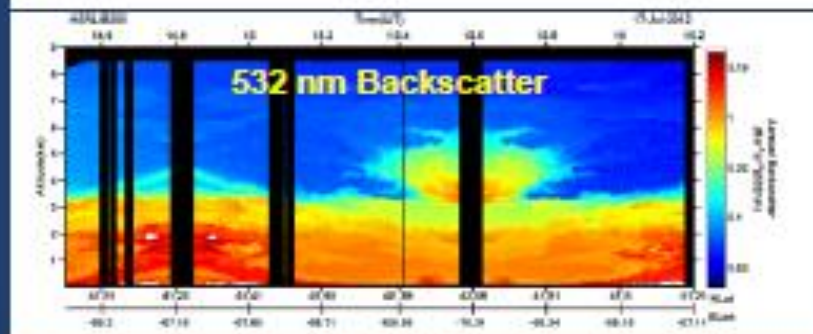
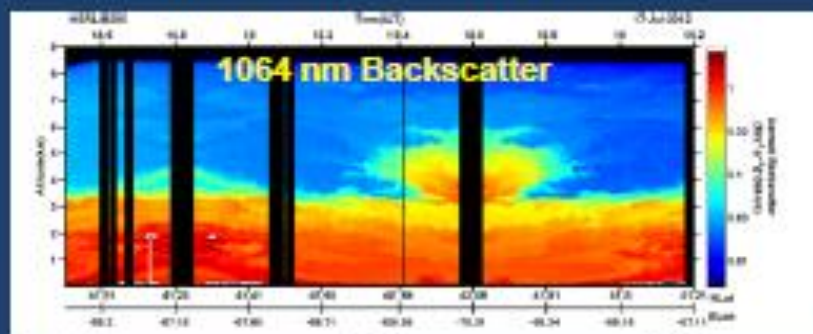
Data SIO, NOAA, U.S. Navy, NG
Image © 2009 TerraMetr
Image IBCAO
Image © 2009 DigitalGlobe



LaRC Airborne HSRL-2: World's First Airborne Multi-wavelength HSRL

07/17/2012 TCAP flight on B200 aircraft

- High Spectral Resolution Lidar (HSRL) provides independent retrievals of aerosol extinction and backscatter
 - HSRL-2 Capabilities
 - Backscatter at 355, 532, and 1064 nm
 - Extinction at 355 and 532 nm (HSRL)
 - Depolarization at 355, 532, 1064 nm





From CALIPSO to HSRL-2 to ACE

Caliop and HSRL*

532 and 1024 nm*

Backscatter

Depolarization

Color ratio

Extinction at 532 nm

Effective radius

Index of refraction

Scattering & Absorption Coefficients

Single Scattering Albedo

*** 2 channel lidar are a minimum requirement to characterize volcanic ash. HSRL is the Calipso airborne equivalent**

Eg. ESA EarthCare mission with a single 355 nm channel will provide improved signal to noise performance for plume heights, limited microphysics, and model trajectory validation. It will also provide greater observation frequency with multiple platforms, but it will not be a sufficiently capable, primary volcanic ash assessment tool.

2/8/2016

HSRL-2 and ACE**

355, 532, and 1064 nm

Backscatter

Depolarization

Color ratio

Extinction at 355 and 532 nm

Mass/extinction ratios

Effective radius

Index of refraction

Scattering & Absorption Coefficients

Single Scattering Albedo

Surface concentration

Volume concentration

Particle size distribution

**** 3 channel lidar are required to directly retrieve volumetric concentration without secondary cal/val.**



UW/NOAA CIMSS Automated Alerts

From: Mike Pavolonis NOAA Federal
Subject: NOAA/CIMSS Volcanic Cloud Alert
Date: May 30, 2014 6:08:15 AM CDT
To: Mike Pavolonis NOAA Federal

@*****VOLCANIC ALERTS*****

STARTING DATE/TIME OF IMAGE: 2014-05-30 10:32:00 [UTC]
PRIMARY INSTRUMENT: MTSAT-2 Vis/IR_Imager
WMO SPACECRAFT ID: 172
LOCATION/ORBIT: GEO
L1 FILE: mtsat02_1_2014_150_1032.area.gz
VOLCANO DATABASE: /data/common//VOLCAT_DATA/alerts/V
NUMBER OF ASH CLOUD ALERTS: 1
NUMBER OF VOLCANIC Cb ALERTS: 0
NUMBER OF VOLCANIC THERMAL ANOMALY ALERTS: 0
NUMBER OF SO2 CLOUD ALERTS: 0

REPORT WITH IMAGES:

<http://volcano.ssec.wisc.edu/alert/report/14318>

POSSIBLE VOLCANIC ASH CLOUD FOUND

Alert Status: New Alert Object
Latitude of Radiative Center: -8.421 [degrees]
Longitude of Radiative Center: 119.678 [degrees]
Mean Viewing Angle: 31.21 [degrees]
Mean Solar Zenith Angle: 100.73 [degrees]
Nearby Volcanoes (meeting alert criteria):
 Sano, Wai(49.71 km)
 Sangeang Api(71.71 km)
 Poco Leok(93.32 km)
 Ranakah(94.86 km)
 Inielika(147.81 km)
Cloud Object Probability: 99.99957 [%]
Median Probability of Object Pixels: 92.45512 [%]
Percent Unambiguous Pixels: 12.30223 [%]
Maximum Height [AMSL]: 10.2 [km] (33355.06 [ft])
90th Percentile Height [AMSL]: 9.6 [km] (31600.68 [ft])
Mean Tropopause Height [AMSL]: 16.5 [km] (54080.38 [ft])
Total Mass: .004477 [Tg]
Median Effective Particle Radius: 5.74 [um]
Total Area: 1281.51 [km^2]

Geographic Regions of Nearby Volcanoes: Lesser Sunda Is
VAAC Regions of Nearby Volcanoes: Darwin
FIR Regions of Nearby Volcanoes: Unknown

Primary Application: Initial Detection, Characterization and Alerting

Potential Secondary Application: Automated cuing of higher resolution observations such as Calipso

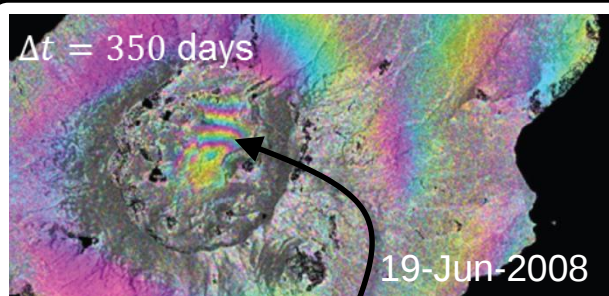
SAR-VIEWS: SAR Volcano Integrated Early Warning System

NASA ASP Disasters Project, PI: FJ Meyer & University of Alaska Fairbanks



- Application of SAR-integrated system to historic eruption of Okmok
 - Conventional AVO data showed hazard signals only 20 minutes before eruption!

– SAR **showed changing deformation pattern 25 days prior to eruption!**



Automatic SAR product shows deformation ~25 days before eruption

Jun 12, 19:40: First seismic signals (only 20 minutes before eruption)

Jun 12, 20:00: Start of eruption

Jun 12, 20:20: First thermal signal in remote sensing data



Eruptive Period

20/06/08

30/06/08

10/07/08

20/07/08

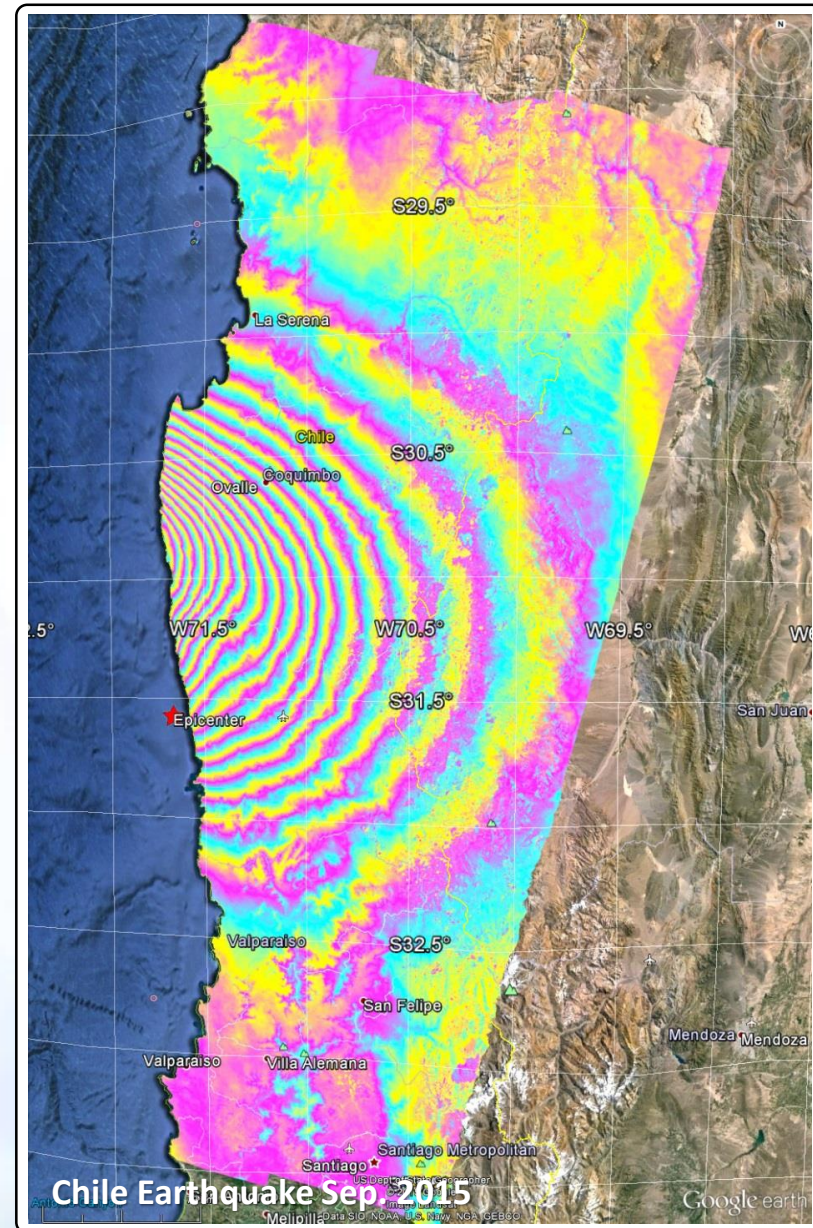
30/07/08

9/08/08

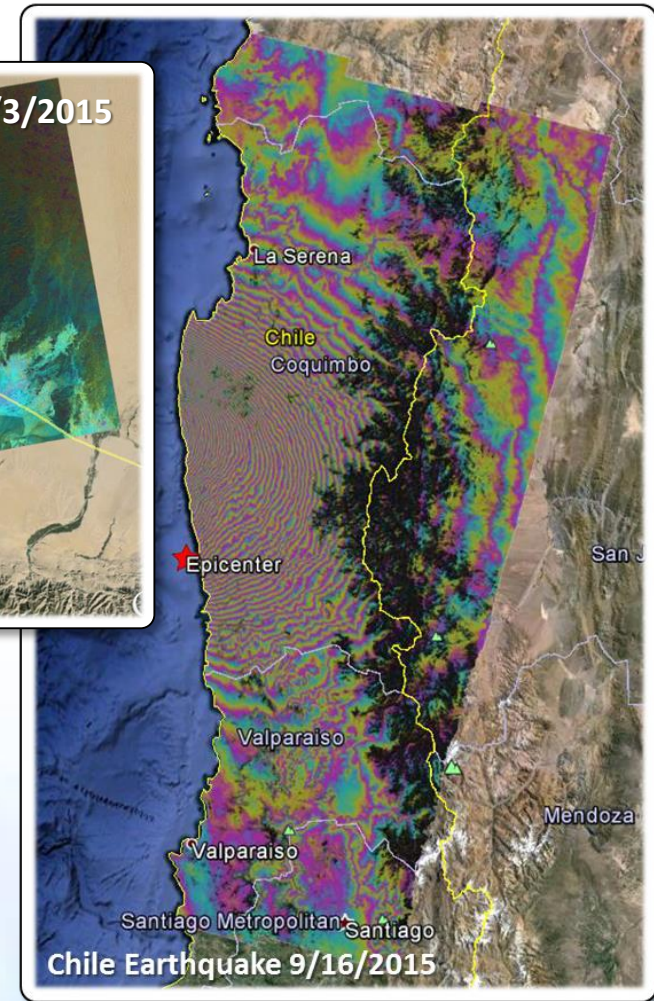
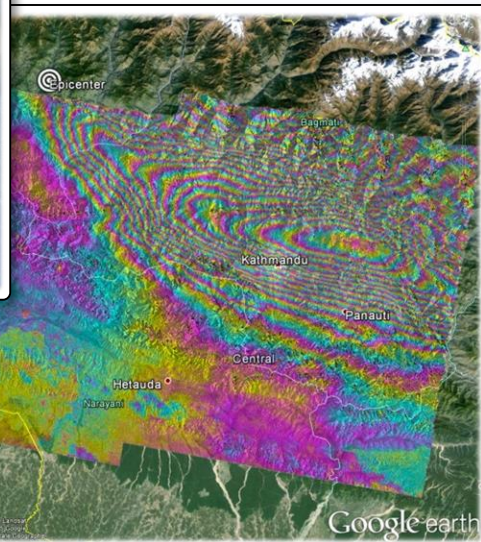
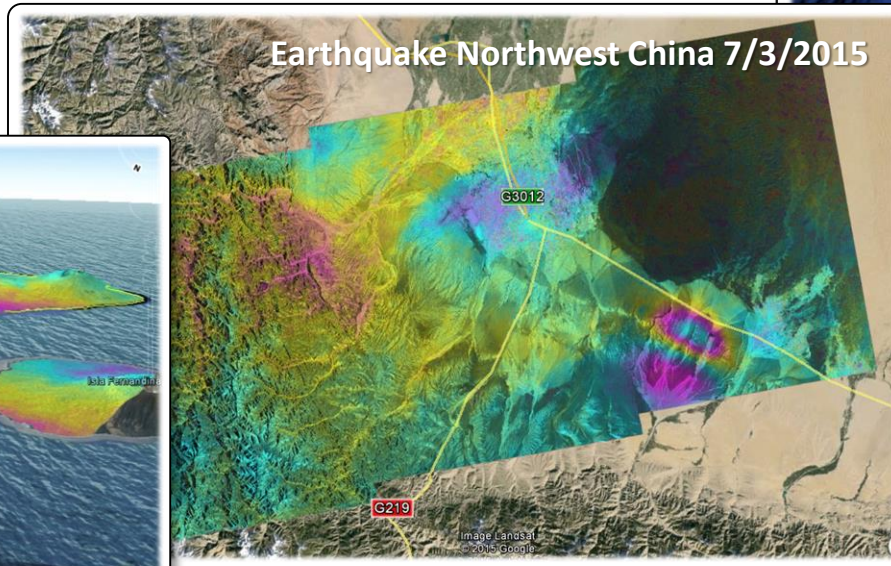
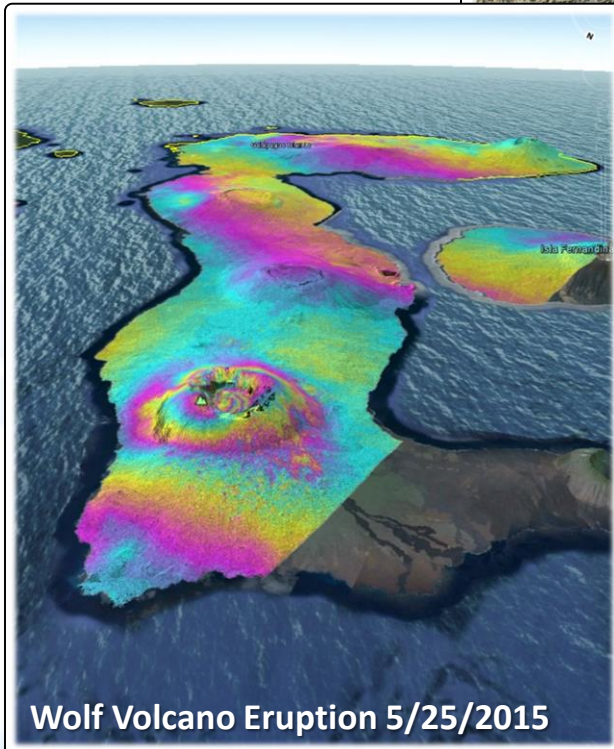
19/08/08

Accomplishment/Result

- While project is aimed at volcanic hazards, we have applied SARVIEWS to disasters of opportunity including:
 - Nepal earthquake (Apr/May 2015)
 - Wolf Volcano (May 2015)
 - Northwest China Earthquake (Jul 2015)
 - Chile Earthquake (Sep 2015)
- **Chile Earthquake (9/16/15; mag. 8.3):**
 - SARVIEWS team completed event-capturing SAR interferogram within 24 hours of the earthquake!
 - Image on right shows up to 1.5 meters of surface deformation across an area of 130 miles radius



Additional Examples



Hazard products for recent disasters:
GIS-Ready Surface Deformation maps

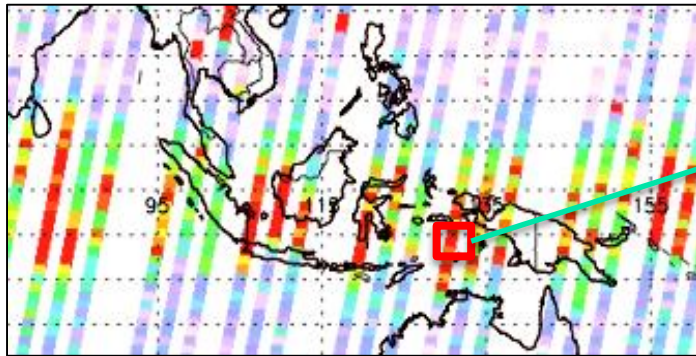


KIAsh deployment after Mt Kelud eruption



(Left). Medium balloon launch with sondes to measure aerosol backscatter. (Right) Preparation of the Optical Particle Counter flight under a large balloon.

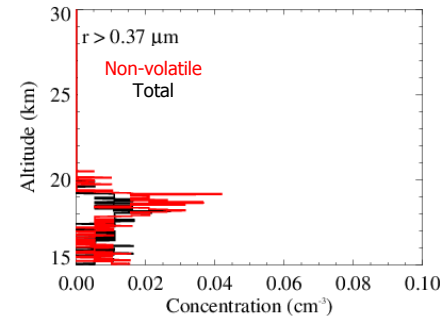
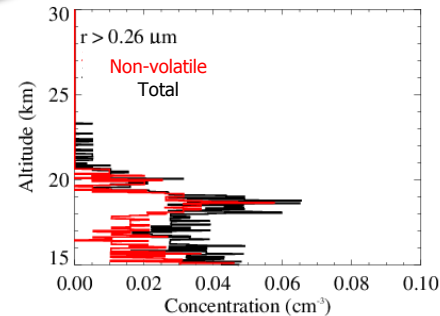
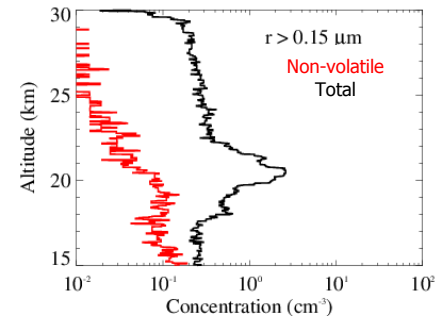
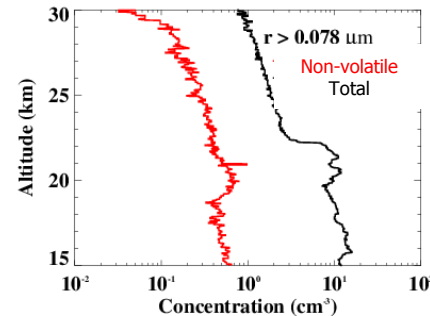
Accumulated CALIPSO observations (14-24 May 2014)



KIAsh campaign

10-day balloon field experiment in Darwin (Australia) May, 2014 to sample volcanic aerosol from the Mt Kelud eruption. *Rapid Response*, with critical support from NASA HQ (Considine, Kaye), CALIPSO (Trepte), SAGE (Thomason), Australian BOM (Atkinson), CASA.

Optical Particle Counter, May 20th



- 3 months after the Mt Kelud eruption, the KIAsh campaign has revealed the persistence of volcanic ash in the lower stratosphere. Current models do not account for the climate impact of volcanic ash.



Marco Fulle - www.stromboli.net



Questions?



Rueters

